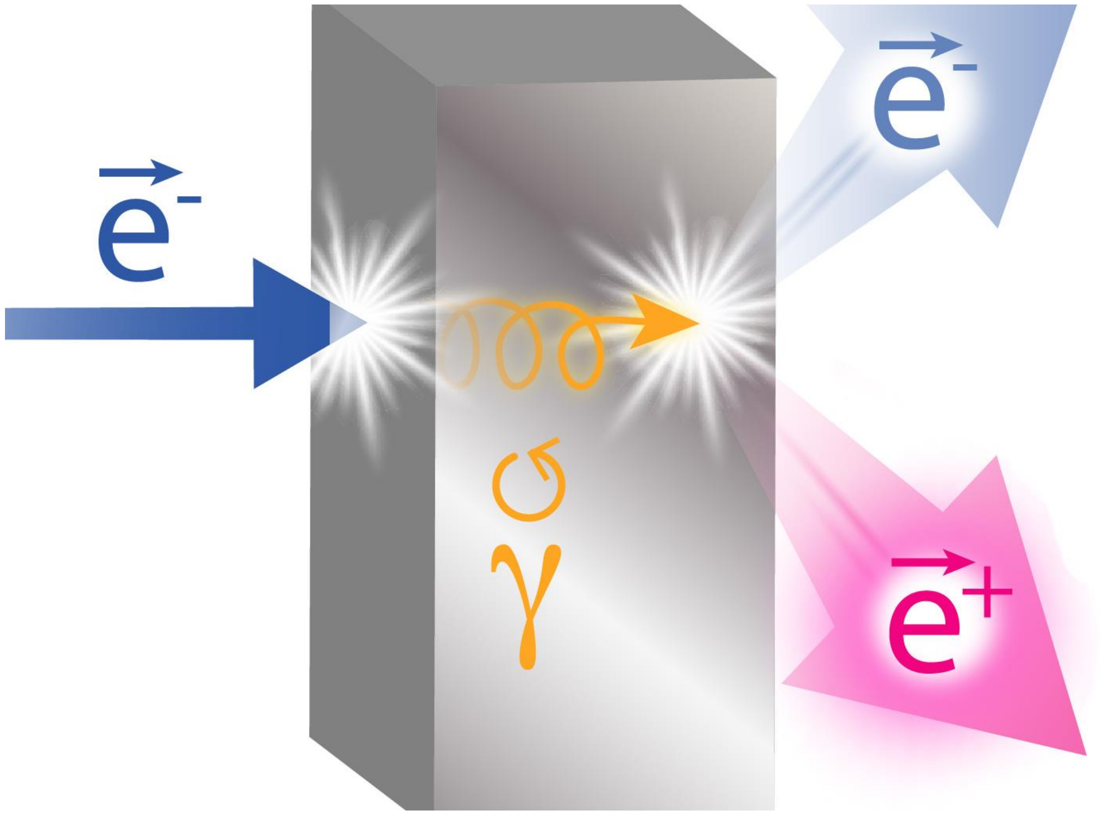
Develop a High-Power, CW Positron Target

2025 NP Accelerator R&D

PI Exchange Meeting



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Project Goal

- The production target for the positron source at $Ce^{+}BAF$ will be a down-select between a liquid metal recirculating target and a rotating solid target
- The project's main goal is to develop and test a prototype for the rotating solid target
- The objectives for the prototype target project are:
  - Vacuum integrity
  - Target rotation and stability
  - Water cooling provided to the rotating target
  - Computational Fluid Dynamics (CFD) simulations benchmarking
- This is a 2-year project

Project Description and Status

- Year 1:
  - CFD simulations
    - Develop a rotating target model and optimize for the following parameters: frequency of rotation, primary beam spot size, cooling water parameters (shape and location of the cooling channel) and contact between target material and its frame
    - The CFD simulations will be developed accounting for the current production target requirements and adapted for the prototype target vacuum chamber
  - Engineering and design
    - Engineer the prototype target design and issue manufacturing drawings for the target assembly
- Year 2:
  - Build, assemble and test a target prototype
    - Procurements for the prototype target assembly
    - Assemble the prototype target in Lab 5 at LERF
    - Test the prototype target with a high power laser (100 – 200 W). Compared with testing the target with an electron beam, the laser heating tests are a much more effective way to thermally assess the target: no radiological issues involved, much faster turn around between measurements
    - Benchmark the CFD simulations

Deliverables and Schedule

- Complete by the end of Jan 2026
  - CFD design, currently at 75% done
  - Mechanical design and engineering, currently 30% done
  - Drawings for manufacturing, currently 5% done
- Complete by the end of Feb 2026:
  - Vacuum system, we established that we can reuse the APEX target vacuum chamber with some refurbishments
- Complete by the end of Mar 2026
  - The rotation mechanism (all components received, inspected and accepted)
  - The water cooling circuit
- Complete by the end of May 2026:
  - The high power laser system (laser box, optics, viewports, laser instrumentation)
- Complete by the end of Jun 2026:
  - Commissioning the prototype target without the laser (motion system, cooling circuit, vacuum integrity)
- End of Nov 2026: complete the laser heating tests and the CFD benchmarking
- We have monthly coordination meetings with LERF SMEs and weekly group meetings with personnel closely involved with the project

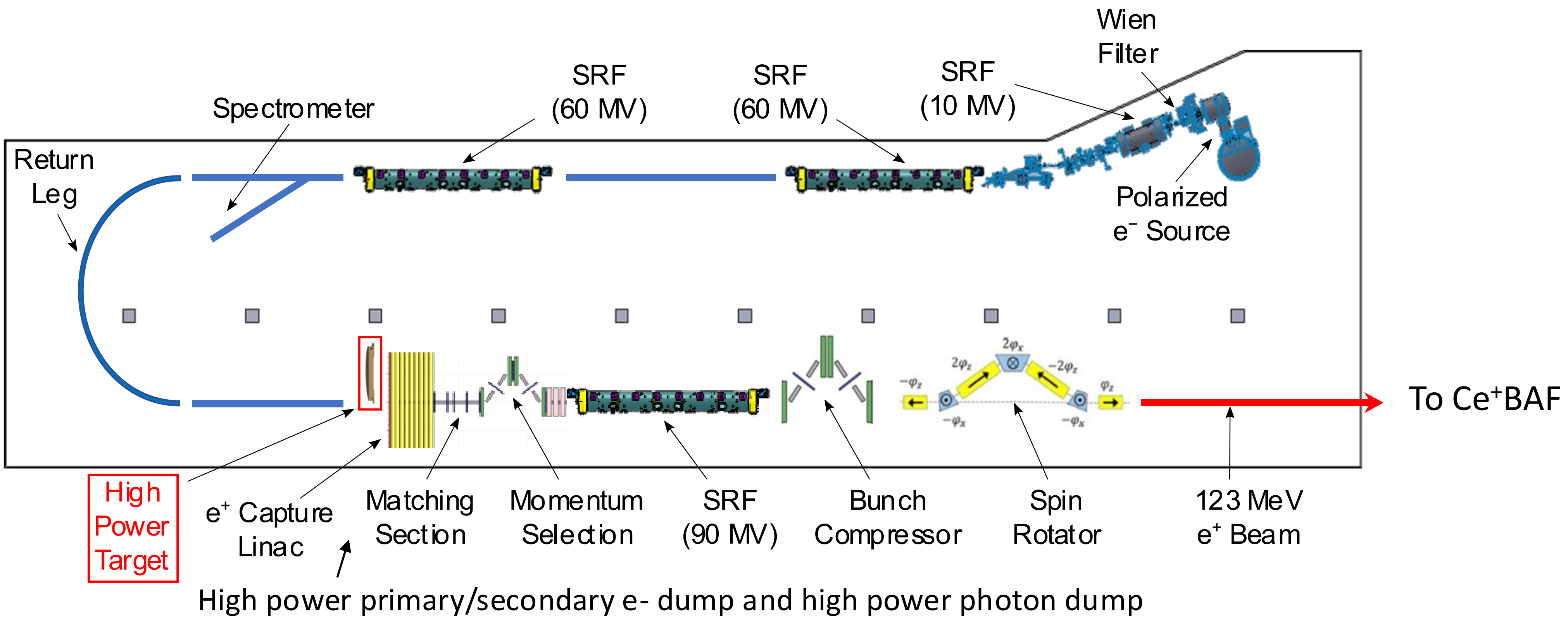
Budget

	FY25($)	FY26($)	Total(AY$)
a) Funds allocated	$220k	$196k	$416k
b) Costs to date	$94k	$0k	$94k

- Funding was received in Q2 FY25, total AY$416k
- Costs Mar – Nov 2025, spent and committed ($AY):
  - $25k on labor
  - $21k non-labor (software licenses and 1 conference)
  - $48k materials and supplies
- The 4-month delay in project funding and the government shutdown diverted or disrupted engineering and CFD resources for about 5-6 months of the 1st year of performance
- We are on track to complete the 1st year deliverables by the end of Jan 2026 and the 2nd year ones by the end of Nov 2026

LERF Polarized Positron Source Concept

- LDRD during the pandemic envisioned the use of LERF infrastructure (300 MeV SRF, e- ERL)
- Design two injectors (e- and e+)
- Develop a scheme to inject into CEBAF
- Provide either e- or e+ on demand



Designing a Production Positron Converter Target

- What do we know about the target requirements?
  - The positron production mechanism, bremsstrahlung followed by pair-production, has an yield of $10^{-4} – 10^{-3}$ positrons for an impinging electron on the target, which means that to produce a positron beam in the range of 0.1 – 1 μA, the electron beam current on target has to be in the range of mA
  - The target should be thick and made from a high-Z material to increase the yield of bremsstrahlung radiation, with thickness in the range $(0.5 – 1.5)X_0$
- Design considerations for a production solid converter target:
  - Stable rotation
  - Effective high-power heat dissipation
  - Operating in a high vacuum environment
  - Thermal simulations benchmarking
  - Thermally and structurally induced stresses, which affect the target's lifetime
  - Radiation damage and degradation, which reduce the target's lifetime
  - Capability to operate in a magnetic field, eddy currents may increase target heating

Prototype target design goals (the first four items above)

$Ce^{+}BAF$ Positron Target Design Goals

- Primary design requirements:
  - High-Z target materials for high positron production
  - Effective power dissipation from 1 mA electron beam with a reasonable lifetime (6 months to 1 year)
  - Maintain a vacuum in the range of 1e-6 Pa (shares the vacuum space with the e- primary source)
- Ensuing goals:
  - Stable target rotation (why rotate the target material: static and linearly moving targets cannot accommodate more than 4-5 kW of heating power)
  - Effective water cooling circuit (why water: it is cheap, a modest flow of 0.5 l/s or 8 gpm can remove 20 kW with a ΔT = 10 K)
- Target materials considered for the production target:
- Materials considered for the prototype target:
  - W, W85Cu15, graphite

material	W (Z = 74)	W85Cu15	Au (Z = 79)
ρ (g/cm^3)	19.3	16.4	19.28
k (W/m*K)	170	196	318
T_l (K)	3695	>1356	1337
X_0 (mm)	3.5	4.44	3.35

- We use CFD to design a suitable geometry that would satisfy the primary requirements and the ensuing ones for a production target, and adapt it for the prototype target chamber

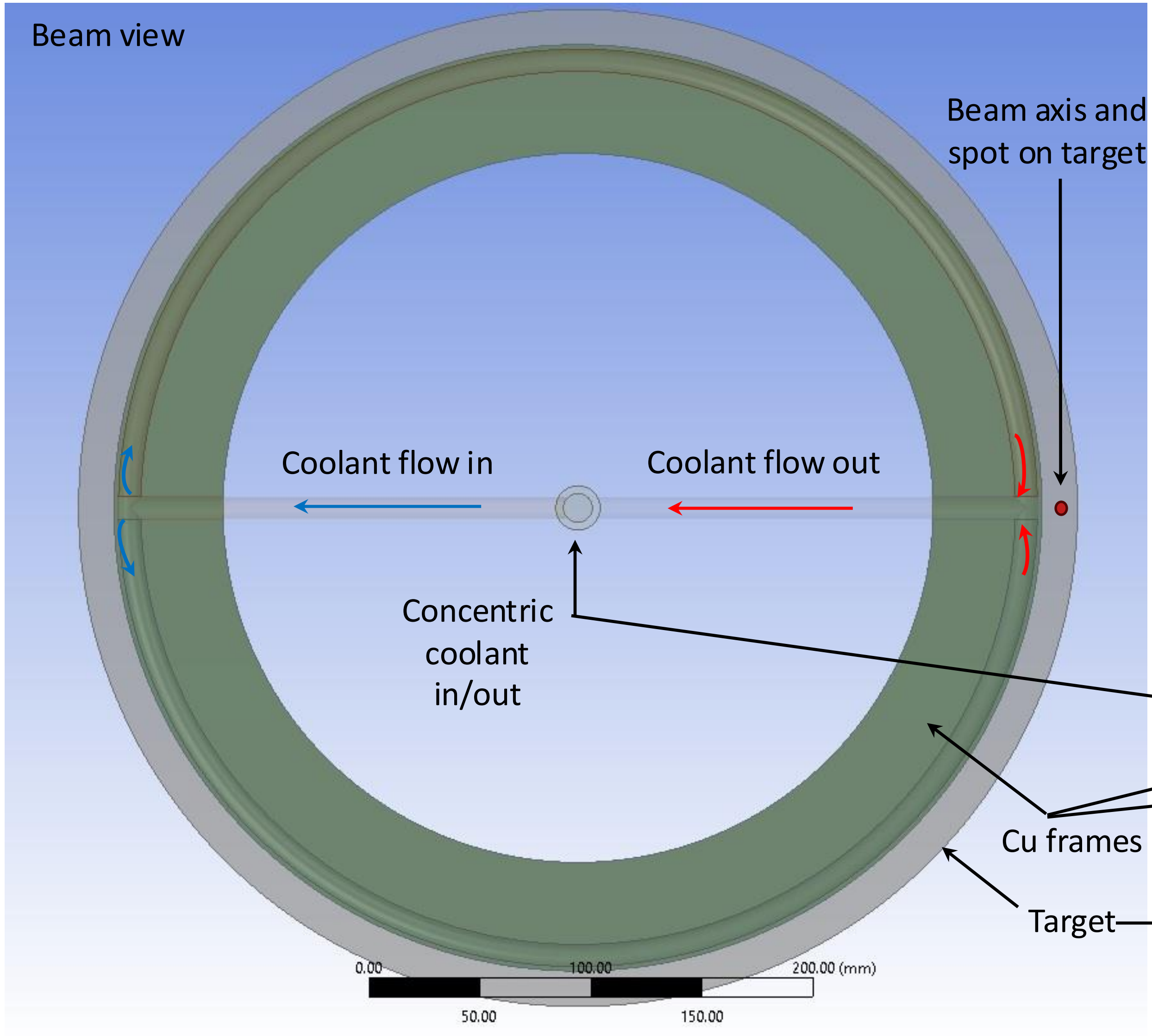
CFD Analysis

- Multidimensional design phase-space with 4 major branches:
  - Geometry: target disk diameter, thickness, contact with frame
  - Rotation: frequency, stability, vacuum compatibility
  - Cooling circuit: effectiveness
  - Primary electron beam parameters: current (1 mA), energy (120, 250 and 370 MeV), spot size (σ: 0.25, 0.5 and 0.75 mm)
- Rotation can be sourced in two different ways in CFD:
  - Static target and rotating beam spot on target (the target rest frame): computationally less demanding, does not account for the effect of rotation on the coolant motion
  - Static beam and rotating target, mimics reality better, accounts for the rotation effect on coolant motion, but it is computationally much more expensive than the previous way
- The target is designed using time-dependent CFD simulations accounting for static beam and rotating target with the electron beam energy loss profile from Fluka calculations
- The CFD calculations are being carried out on a dedicated CFD farm at Jefferson Lab, using 8 compute nodes (up to 512 CPUs)
- The CFD software is ANSYS-Fluent

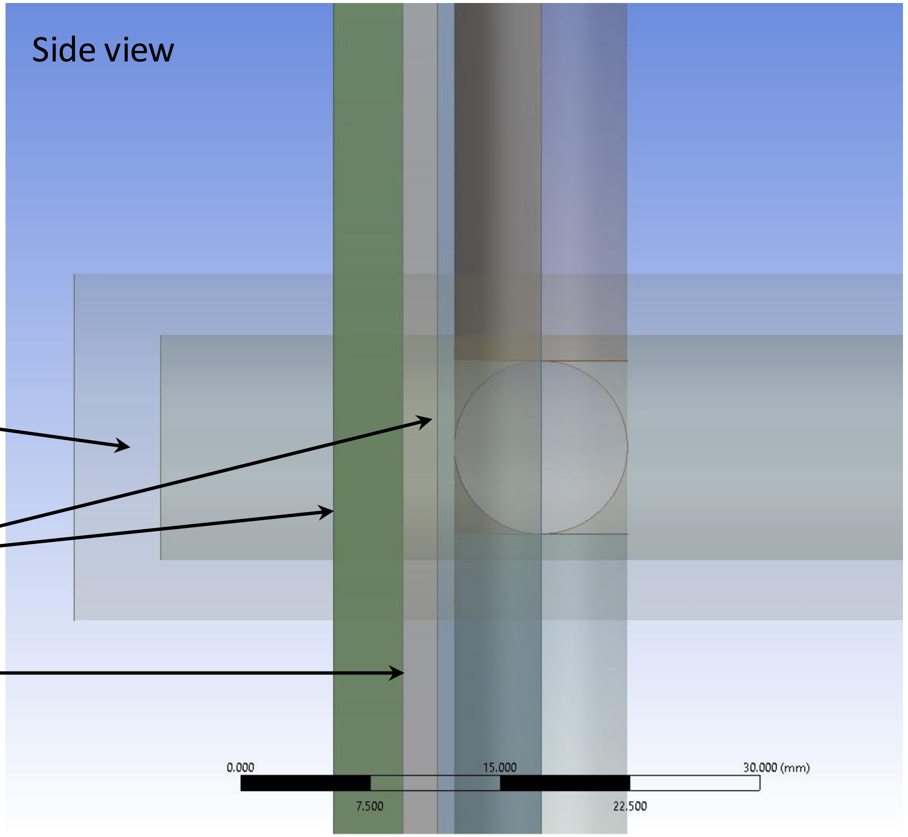
CFD Status

- A static W target could accommodate 1 kW, while a linearly moving one 4-5 kW of heating power before they melt
- A target rotation with a low frequency, less than 10 Hz, would suffice to keep the maximum temperature less than 1000 K for a target with a diameter at least 30 cm and a beam spot 2 mm in diameter
- 3 major geometry designs considered for a rotating target
  - Model 1: coaxial cooling circuit for water in/out distributes the coolant in a toroidal cooling channel/tube close to the rim of a copper disk. The target material is sandwiched between two copper disks. The cooling circuit rotates along with the target material
  - Model 2: the target disk rotates inside a static casing with water jetted in/out of the casing. The cooling circuit is static
  - Model 3: similar to model 2, the casing rotates, the target material is welded to the casing, as a beam "window". The cooling circuit is static
- The design considered for the prototype target is model 1, version 9

Model1 Geometry

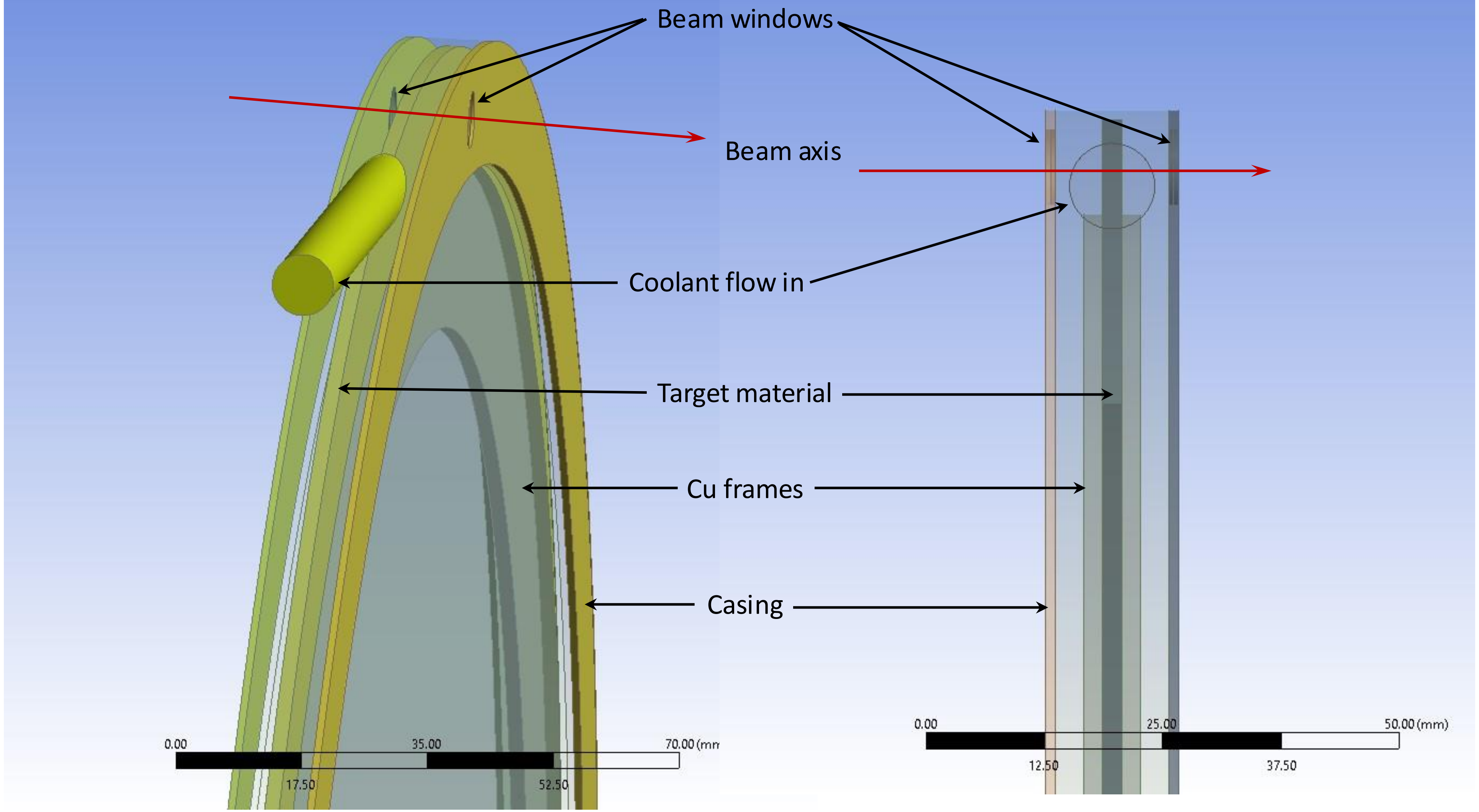


- 9 geometry models assessed with CFD, 450 mm diameter target
- Annular target material sandwiched between two copper disks



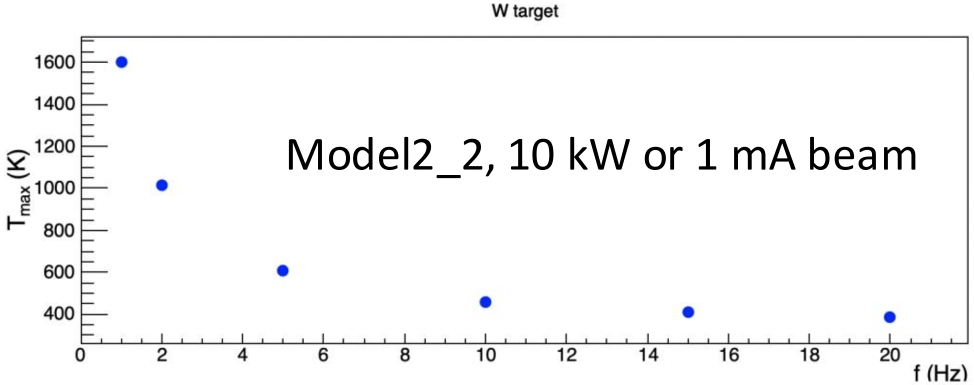
Models2 (and 3) Geometry

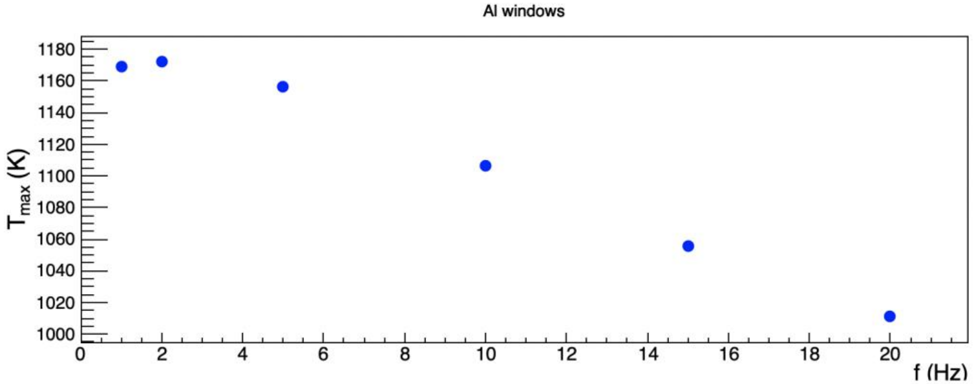
- 450 mm diameter target wheel

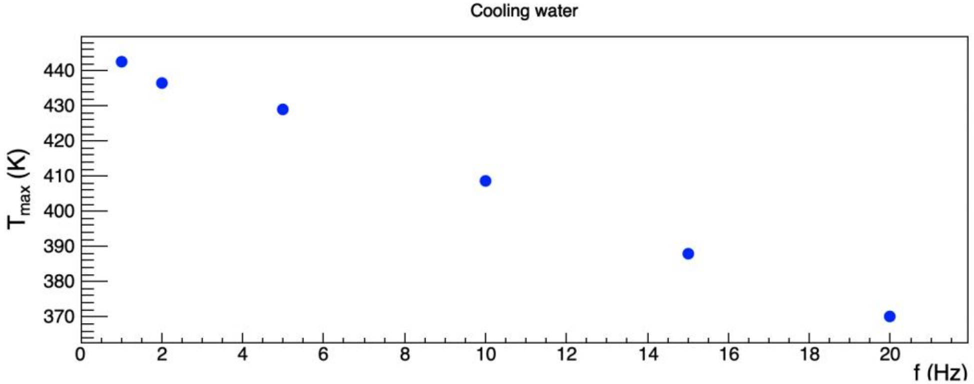


- The target wheel rotates inside a fixed casing. The coolant lines in/out connect to the casing and are fixed, do not rotate
- The target material is sandwiched between two copper disks
- The casing has thin windows for beam (considered to be made of Al for these simulations). The Al windows are fixed
- The primary beam traverses the coolant, the casing's windows and the target material
- This design simplifies the engineering of the coolant circuit
- 5 geometry variations were assessed with CFD

Model1 and Model2 Designs Compared

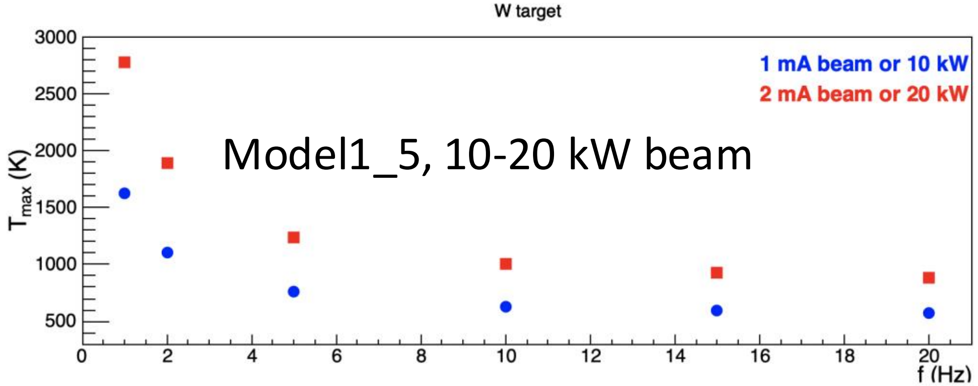


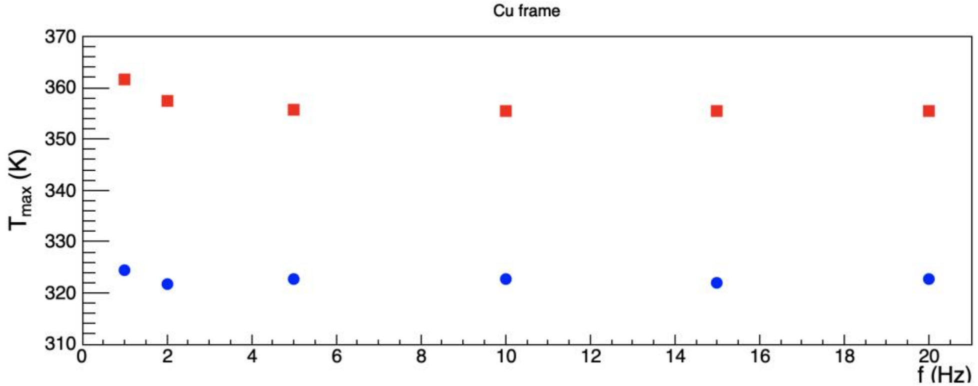


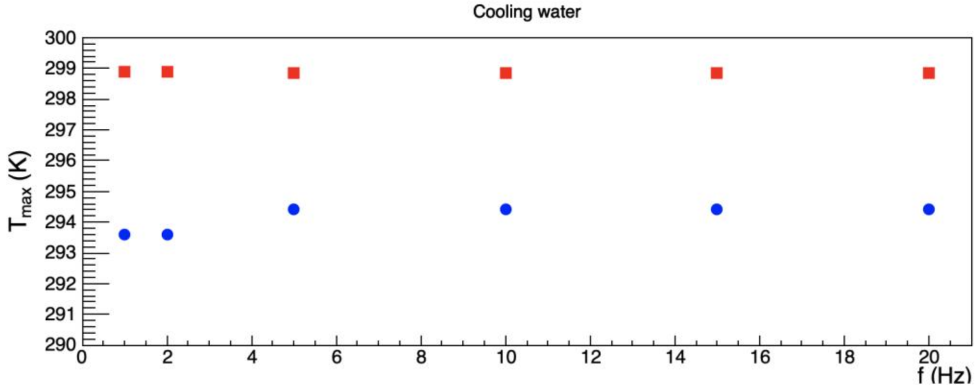


Gaussian beam spot profile, with σ = 0.5 mm for both models

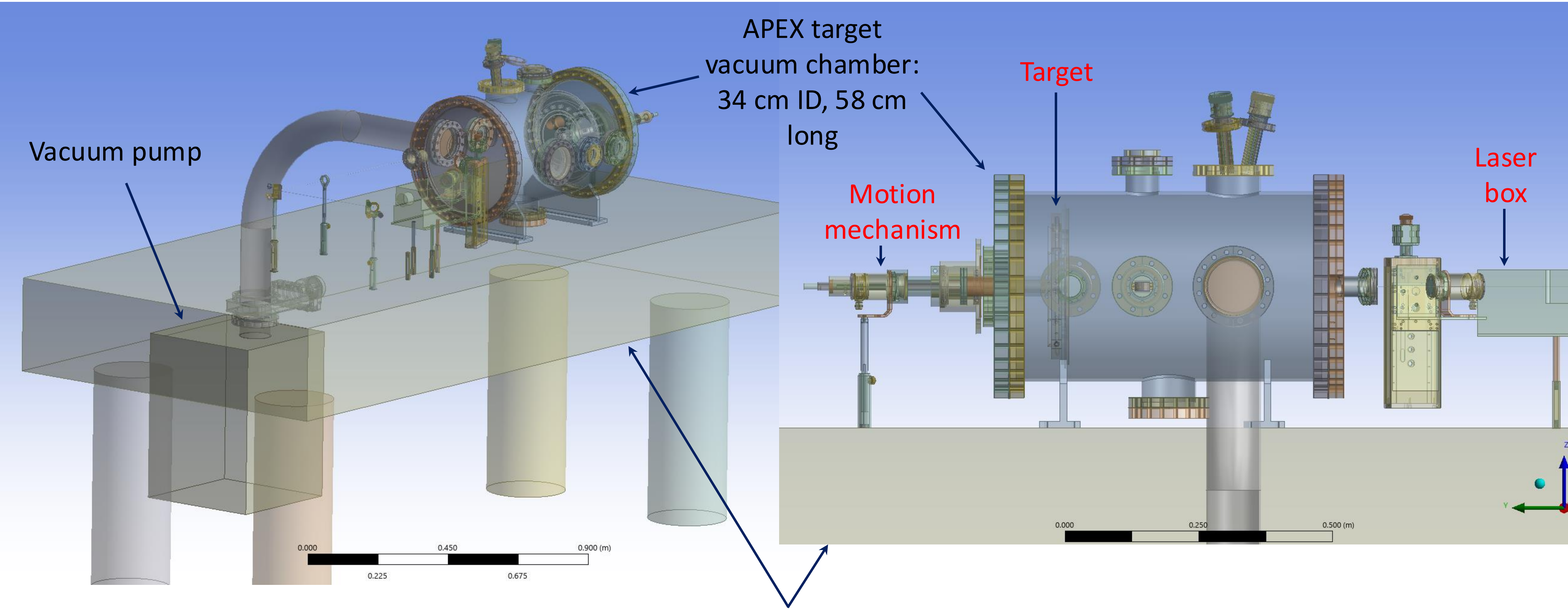
The target material thickness is 2 mm







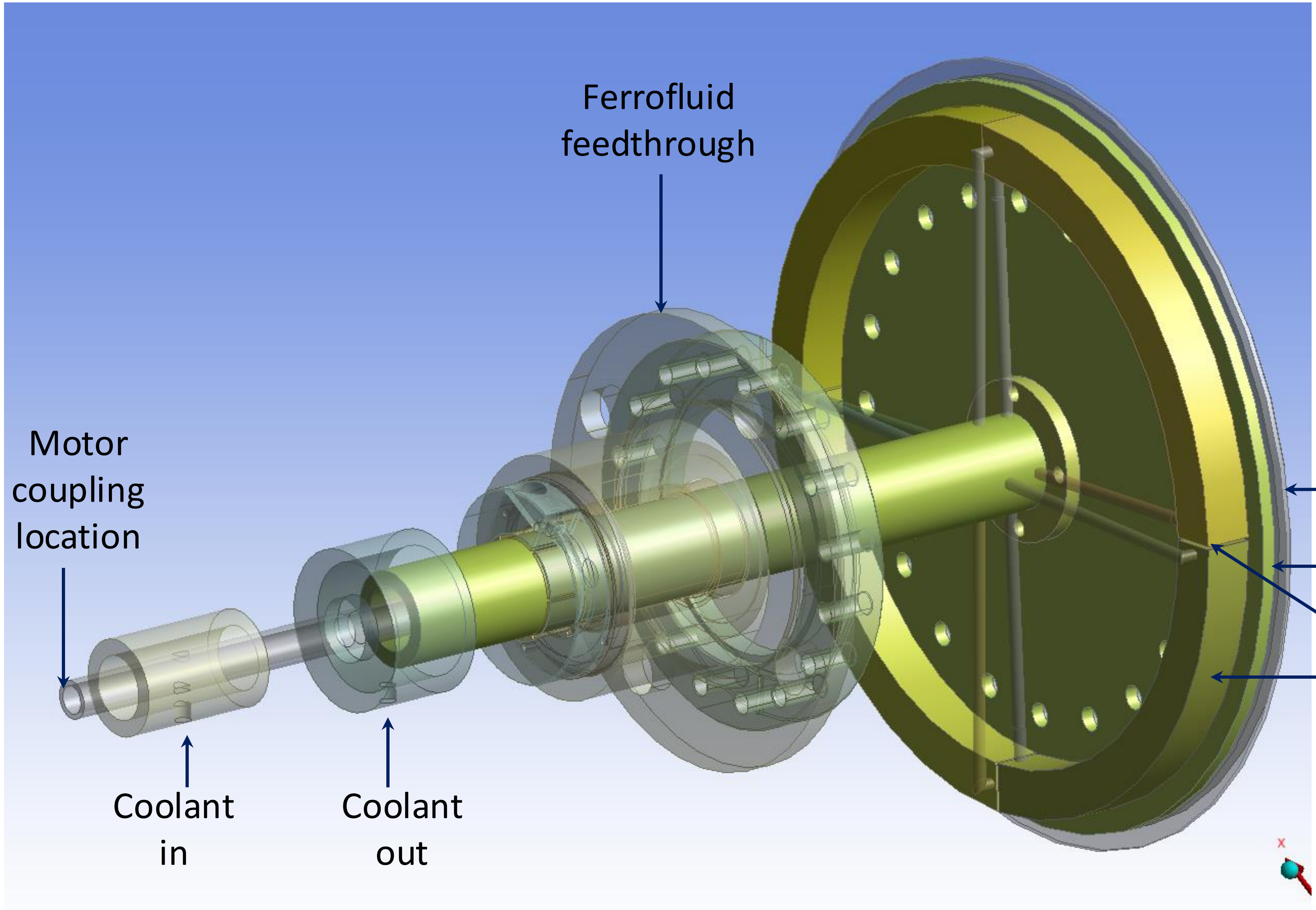
Prototype Target Assembly



Black = existing

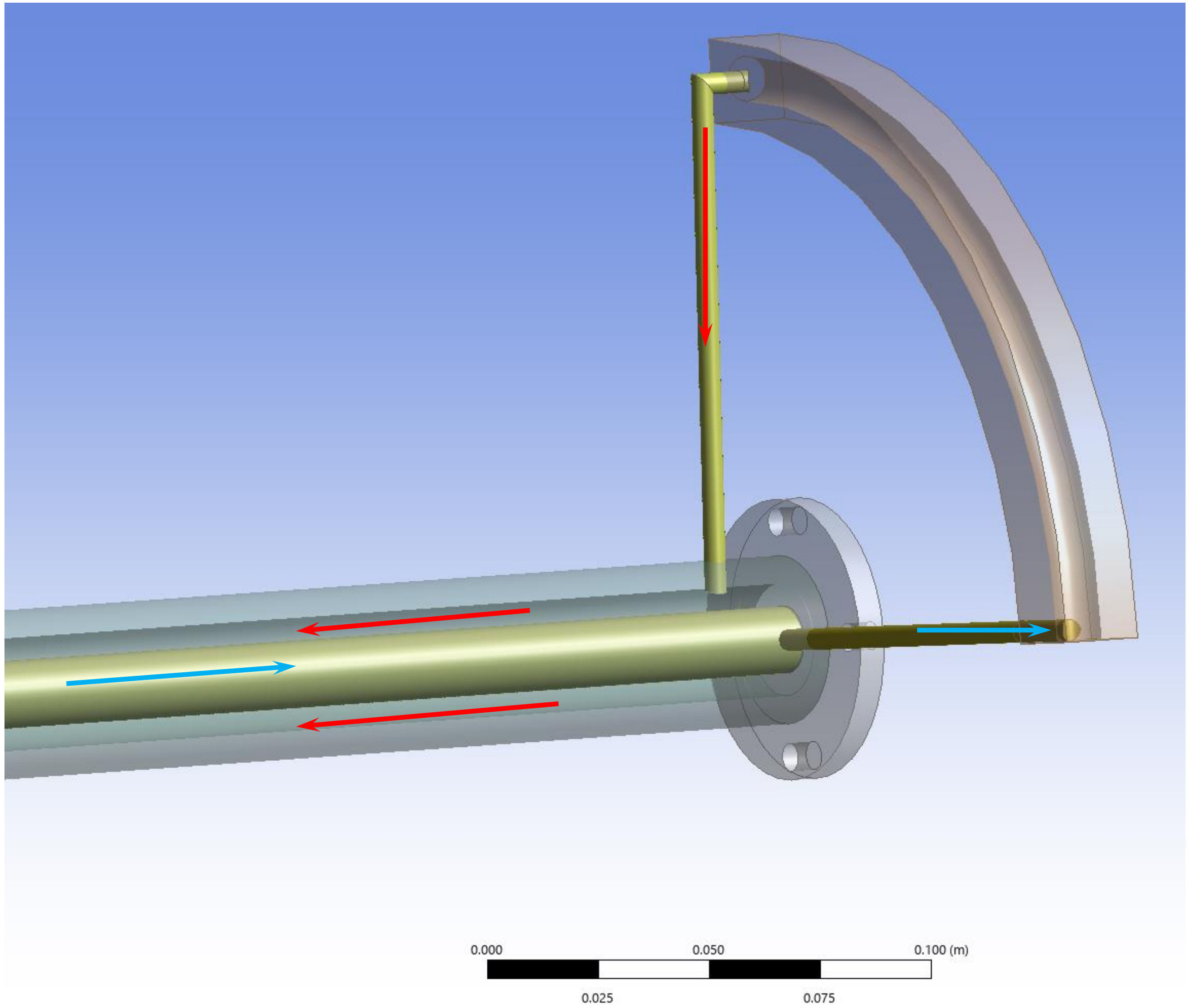
Red = new

Rotation Mechanism for the Prototype Target



- The motion mechanism will afford stable rotation in vacuum up to 10 Hz through a ferrofluid feedthrough rated for 10^{-6} Pa
- The target disk is sandwiched between two copper disks/frames, which a bolted together

Coolant Circuit for the Prototype Target



- Coaxial inlet/outlet coolant circuit
- There are 4 quarter-circle rectangular copper coolant tubes (made from high-current magnet wire) that will be brazed to the half of the copper frame/disk supporting the target material disk

- A quarter cooling channel shown to the left, the arrows show the direction of the water flow (blue = cold water, red = warm water)

- The cooling circuit can accommodate water flows up to 1 kg/s with a pressure loss of less than 8 psi. We plan to operate it with a flow of less than 0.5 kg/s and expected pressure loss of 2 psi
- A water chiller rated for 500 W heat removal would suffice for the prototype target

Summary

- We are developing new CFD tools to design targets with effective high power heat dissipation in thee range of 10-20 kW
- We are on track to achieve the first year goals by the end of Jan 2026: to have a mature CFD design of the target at the 90% level, and to complete the engineering and mechanical design
- We started working on the year 2 goals
- Two Old Dominion University graduate students will do their theses on the development, assembly, high power laser testing and analysis of the prototype target
- The prototype target is a stepping stone towards a production positron converter target at Jefferson Lab